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PROBLEMS OF THE RECOGNITION AND EVALUATION OF THE EFFECTS OF GASEOUS AIR IMPURITIES ON VEGETATION

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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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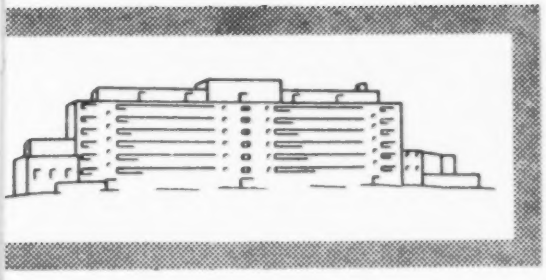

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PROBLEMS OF THE RECOGNITION AND EVALUATION OF THE EFFECTS OF GASEOUS AIR IMPURITIES ON VEGETATION*

by

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Preface

This paper represents a philosophy of approach held by many of the German workers to the problem of evaluating the effects of air pollution on vegetation. The present translation is offered because it is felt that wider circulation to the English speaking workers in the field may be profitable.

It is interesting to note that while this paper is based upon interest in the sulfur dioxide problem, this toxicant is not named. It is implied in the use of the term Rauchschäden (smoke damage) and in the references to the work of O'Gara and Hill and Thomas. The implication is that this approach is applicable to all gaseous phytotoxic air pollutants. Conversations and correspondence with other German workers would indicate that this view is widely held.

The distinction between "injury" and "damage" is not basically unique with these workers. However, I know of no publication which makes the distinction quite as emphatically. The semimathematical treatment of the various relations considered by these workers to be involved in the distinction between injury and damage may not find as general an acceptance. The approach is worthy of consideration and may stimulate further work in this area.

The Forschungsinstitut für Luftreinhaltung e.V., (formerly Kohlenstoffbiologische Forschungsstation, e.V.) is the principal German institute interested in the general problem of air pollution as it affects vegetation. The institute leader is Dr. Heinrich Strätmann.

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PROBLEMS OF THE RECOGNITION AND EVALUATION OF THE EFFECTS OF GASEOUS AIR IMPURITIES ON VEGETATION

Damage to vegetation by gaseous air pollutants can be controlled only by proper recognition and evaluation of the immissions[1] that are injurious to vegetation. For this reason the quantities of injurious substances, as determined by air analyses, must be related to their possible injurious effects. The problems of establishing these relationships are the subject of this discussion. Since the evaluation of an injurious effect depends on the definition of "damage," we will begin with a discussion of this point.

1. The Concept of "Damage"

The recognition and evaluation of vegetation damage presupposes a precise definition of the concept of damage. Previously accepted was the general opinion of Tiegs (1) that smoke "damage" includes all the injuries and upsets of vital activity of the plant resulting from the immissions. Usually a distinction has been made between acute and chronic injuries; beyond this, some authors (2,3,4) have added the category of invisible injury. Without going into the details of the practicability and justification of this classification, it should be noted that earlier attempts to determine "damage," both in form and in extent, have met with great difficulties. In our opinion this can be attributed to the fact that "injury" was equated to "damage." The term "injury" should be considered to include all plant responses resulting from the action of air pollutants. Temporary reductions of assimilation rate or alterations in content of plant constituents thus are included, along with leaf necrosis, leaf abscission, or retarded growth. Of the many functional disturbances and dramatic visible effects that can result from air pollutants, only those of significance to the desired use of the plant should be considered damage. On the basis of this concept we assess the useful

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[1] The German workers use the term "immission" in reference to the amount of pollutant as it relates to a receptor and the term "emission" in reference to the amount of pollutant as it relates to a source. In translating, we have maintained the distinction by adopting the term.

value of a plant according to an ideal, an economic, or eventually a biocoenotic point of view.

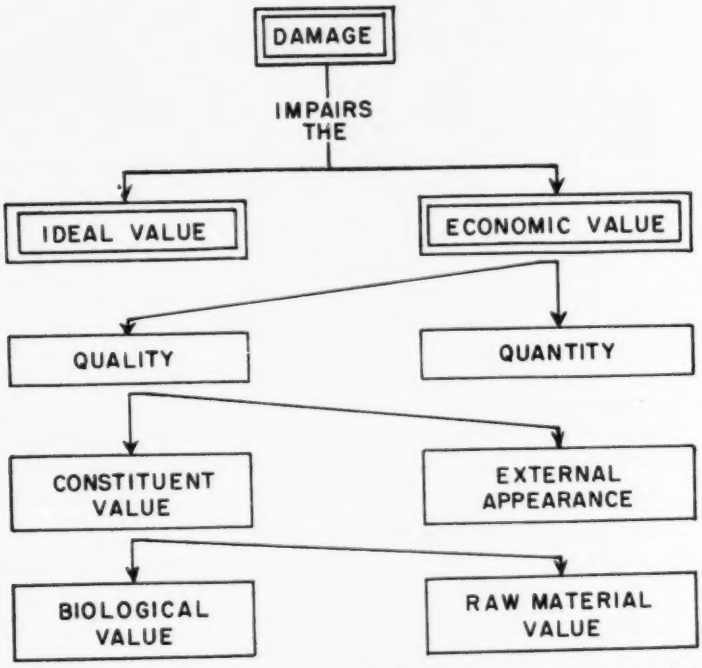
The need for differentiation between injury and damage rests on the following considerations. A single gas fumigation, for example, can produce a similar acute injury in the form of leaf necrosis on spinach, fodder turnips, and ornamentals. Despite the visually comparable extent of the injury on the three crops, the effect on their useful value may be markedly different. The leaf injury to the turnip need not affect the profit from the root crop. The value of the spinach and ornamentals, however, will be markedly reduced by the necrosis. Thus, the evaluation of damage must be directly related to the use of the plant. In this example the damage to the turnip can be assessed only in terms of root yield, whereas with spinach there is a further matter of nutritional quality, and with the shrub, a matter of appearance. As a consequence, it is possible that no monetary loss would occur with the turnip if the injury did not affect the yield, but any leaf injury could result in a loss in the case of the spinach and the ornamental shrub. The damage to the latter two plants should be further differentiated because the useful value of the spinach includes not only appearance but also its nutritional quality. It is not sufficient to judge the spinach solely on the basis of yield and appearance, although today this universally determines market value; rather, the effects of the injury on a biological value expressed as "the sum of all the nutritionally and physiologically important constituents" should be investigated (see Figure 1).

In summary, every injury need not necessarily result in damage. Only those injuries and functional disturbances that have a detrimental influence on the ideal or economic useful value of the plant are to be regarded as damage.

2. Methods of Evaluating Damage

Although by our definition injury may be identical to damage, other relations also exist. These have been diagramed in Figure 2. In order to deduce directly from air analysis data a degree of hazard to vegetation, the relation between injury and damage must be defined clearly. To this end we have indicated three relationships.

1. If the injury directly reduces the value of the plant, as in the case of leaf necrosis on an ornamental shrub, the injury is considered identical with damage.

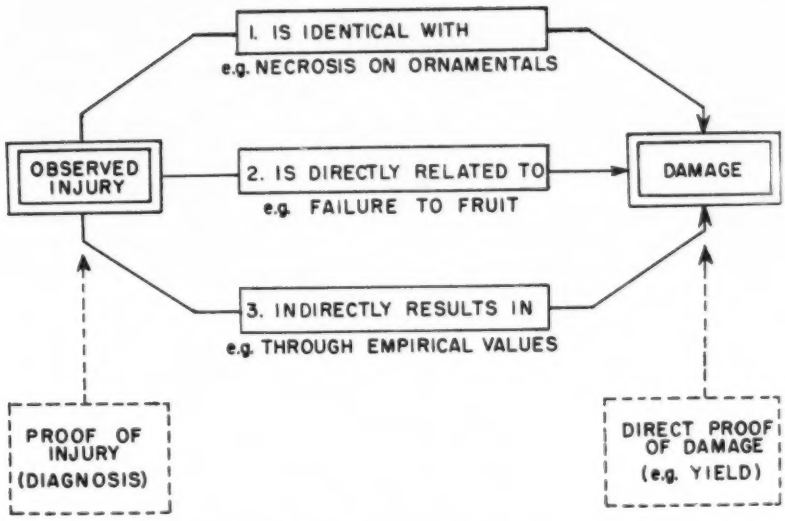


POSSIBLE AIR POLLUTION DAMAGE TO VEGETATION.
FIGURE 1.

2. If the injury conditions a definite loss, as in a failure to fruit, the injury is considered to produce direct expression of damage.

3. If, as with many injuries, the damage can be deduced only through empirical values, the injury is considered to produce an indirect expression of damage.

As indicated in Figure 2, direct damage can sometimes be proved, e.g., through determination of yield. From the relationships shown, we are able to assign for various plants "critical development stages," during which, within



RELATIONS BETWEEN INJURY AND DAMAGE.
FIGURE 2.

limits, an injury definitely results in a loss of profit or return.

The methods necessary to prove injury must allow for the many forms of injury. We must use various methods of proof, therefore, with one and the same growth, since we do not have a specific damage test at our disposal. As yet, no existing criterion is in itself capable of providing clear information concerning an injury and its effect upon the final value of a plant.

The very obvious discoloration of leaves as well as necrosis from acute and chronic injuries are no more characteristic than, for instance, the sulfur content of the individual organs of a plant or the water-soluble iron content or, alternatively, phaeophytin (5,6,7,8). No single characteristic will suffice to make a positive diagnosis. With several indications, however, we are in a position to prove injury, and the greater the number of individual features, the more certain is the proof. Consequently, it is necessary to determine as many individual constituents as possible. The search for new methods of

proof must be continued, and to this end, the course followed by Hartel (9) appears to give promise of success. Although his determination that smoke-damaged pines isolate certain substances applies only to this type of growth, a step has been made in the direction of a specific damage test. Such a test should be more easily discovered than one that applies to families or even class species.

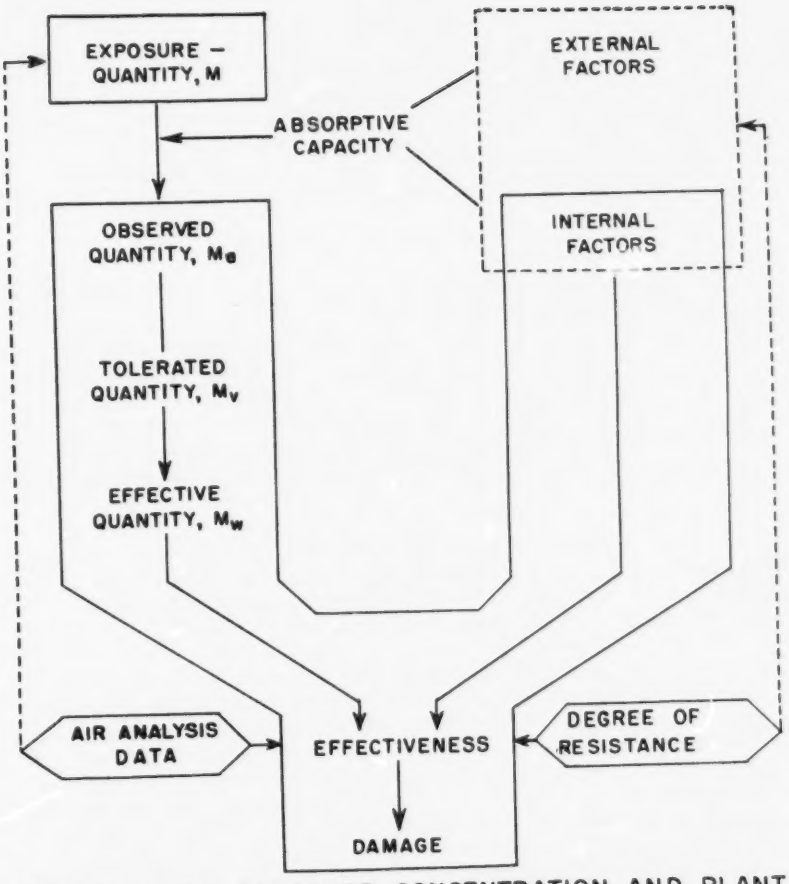
Inadequacies of the methods of proof thus necessitate seeking new ways whereby particular attention will be drawn to the cellulose content, the cellulose fiber, tannin substances, alkaloids, compositions of the plant ash, the caloric nutrient substances (protein, fats, carbohydrates), and the acaloric effective and protective substances (flavors, vitamins, mineral salts). In some cases the biological valence will have to be determined.

3. Prevention of Damage

As has already been stressed, damage can only be prevented by the proper recognition of immissions that endanger vegetation. The first thing, therefore, is to clarify the question of a connection between immission and injury. The detrimental effect of a gaseous air pollutant upon vegetation depends not only upon the concentration of the injurious substance and the exposure time, but also upon the capacity for resistance inherent in the plant (see Figure 3).

Air analysis gives only the quantity of the injurious matter, M, in the air. Only a part of this quantity is absorbed by the plant. The amount absorbed, M_A, is determined by both internal and external factors.

A part of the injurious matter absorbed can be considered as tolerated. The small variation in the stimulus threshold values of different varieties of plants indicates that this tolerated quantity fluctuates only slightly. Only those quantities of toxicant that exceed the level of tolerance cause injury and are designated as the effective quantity of toxicant M_W. This represents the difference between the amount absorbed and the amount tolerated. Equal effective quantities of toxicant may, however, produce different effects, depending upon the nature of the plant, its inherent specific resistance, and environmental factors. We have designated the effect of this effective quantity of toxicant as being the damage effect, W. All internal and external factors that determine the ability of the plant to resist the toxicant are expressed in terms of degree of resistance, which changes to a varying extent with the stage



RELATION OF EXPOSURE CONCENTRATION AND PLANT RESISTANCE TO VEGETATION DAMAGE EFFECTS.

FIGURE 3.

of development. The damage effect is, therefore, not only a function of the quantity of toxicant absorbed but also one of the degree of resistance.

Returning to the initial requirement of defining the relationship between air analysis and damage, we first must answer this question: What concentrations of gas and periods of exposure will cause no injury under any circumstances? This is the amount of toxicant that can be tolerated, or the irritation threshold concentration, C_R. This is defined as the concentration that is not injurious under conditions of continuous exposure. This concentration varies slightly with respect to culture conditions. In order to obviate damage to all cultures, the air concentration must always remain below the irritation threshold of the most sensitive plant. For practical purposes, however, the mean irritation threshold of the most sensitive plant under a variety of conditions should suffice. This limit is designated as the first tolerance limit and logically applies to all of the vegetation of an area, in all periods of growth. The no injury condition demands, however, that the first tolerance limit not be exceeded at any time. As a consequence, the air analysis data required to check compliance with this condition must be obtained under short measuring-time intervals. This can be represented by use of Δt as the specific time value in the relation $\frac{C_R}{\Delta t}$, for instance mean values determined at intervals of a maximum of one hour.

If the irritation threshold concentration is exceeded, then the quantity of toxicant in excess of the amount tolerated will have an effect. In order to judge whether this excess may result in damage, we define a further characteristic quantity, namely, the second tolerance limit. For this we have on the one hand the values measured by air analysis (concentration fluctuations, frequency, duration of effect, and total time of exposure) and on the other hand all factors that affect the resistance capacity of the individual plant. Thus, for a competent judgment of the effectiveness of a toxicant, two characteristic values are necessary--a value measured by air analysis and an influence value that combines all resistance factors. The values from both these areas must be combined in a manner that will permit a decision regarding the possibility of damage resulting in any specific case.

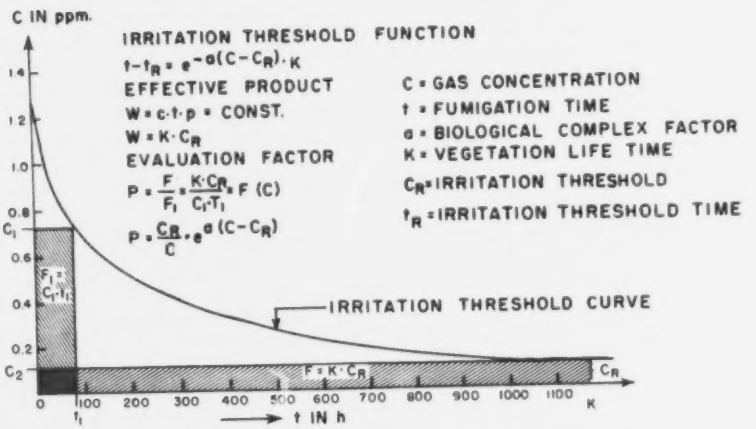
The significance of the concentration, C, and the exposure time, t, on which O'Gara (10) derives his function

$$(C - C_R) \cdot t = \text{constant}$$

is generally known. (11,12) This relation implies that equal products of $(C - C_R)t$ will produce equal damaging effects, or in other words, concentration and exposure time are set indirectly proportionate to each other. Observations by our group (13) do not agree with this relation, however, since doubling the gas concentration had a greater effect than doubling the exposure time. In order to allow for these observations, the influence of concentration must result in a higher value than in the simple O'Gara function. From other work (14) the exponential function,

$$t = K \cdot e^{-a(C-C_R)}$$

seems to give an adequate description of the data. Following this form, we obtain irritation threshold graphs (Figure 4) that approach each other asymptotically for



IRRITATION THRESHOLD FUNCTION. DERIVATION OF EFFECTIVE PRODUCT W AND EVALUATION FACTOR P.

FIGURE 4

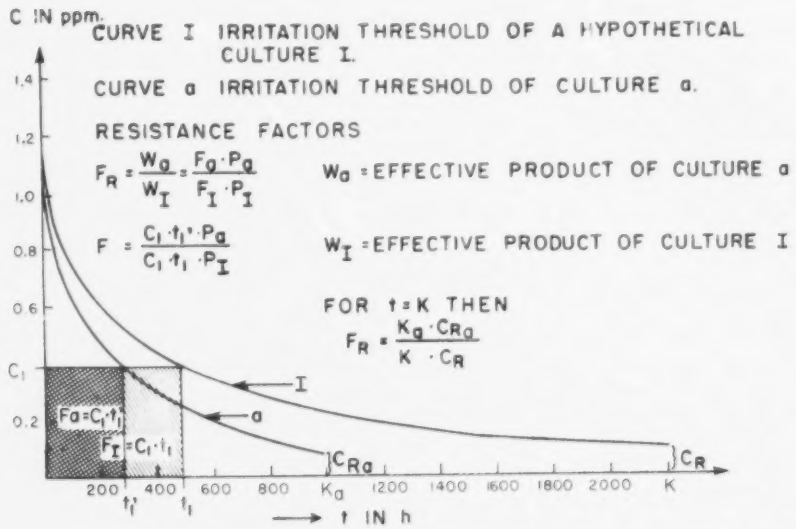
each individual species of plants in the range of higher concentrations. This agrees with the observation that at high toxicant levels differences in the resistance of the plants lose their importance. For low concentrations with

correspondingly long periods of exposure, the graphs of the function break off at the irritation threshold.

As diagramed in Figure 4, pairs of characteristic values C and t do not give a constant product, but the product becomes smaller with increasing concentration. However, taking all the pairs of C and t that can cause injury, in relation to a product $K \cdot C_R$, one obtains a quotient that can be presented as a function of concentration. We have designated this as the evaluation factor, P. If one multiplies individual C·t products by the evaluation factor, P, the resultant value along the irritation threshold curve is a characteristic value we designate as the effective product, W,

$$W = C \cdot t \cdot P$$

The effective product depends upon the developmental stage of the plant as well as the cultural conditions. From the effective product for various culture conditions and their relationship to one another (Figure 5), we can



DERIVATION OF THE RESISTANCE FACTOR F_R

FIGURE 5

define a resistance factor, f_R. This resistance factor includes all those characteristics that influence the absorption of the toxicant and its ultimate effect on the plant.

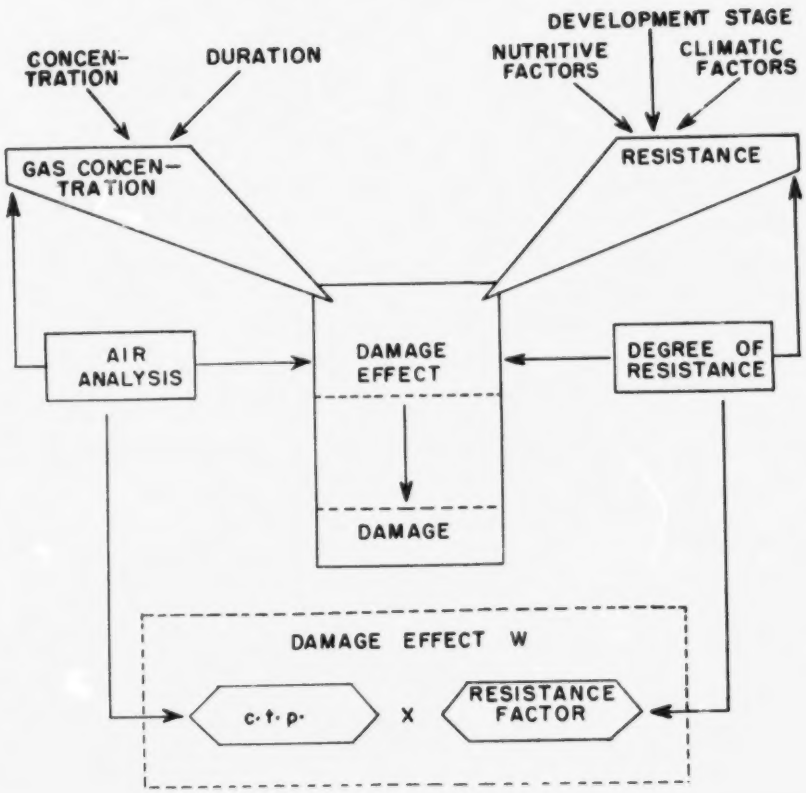
Each plant culture has a specific resistance factor that must be derived from observational data. For limiting purposes, we define a hypothetical culture with an irritation threshold concentration identical with the first tolerance limit. This hypothetical culture satisfies the irritation threshold function during the entire vegetation period. These conditions are probably not fulfilled by any plant under normal cultural conditions. Nevertheless, we can now give expression to deviations from this hypothetical culture by means of the resistance factor. If one takes the resistance factor, $f_R = 1$, for the hypothetical culture, one can derive the effective product, W, from the irritation threshold function. On the basis of these assumptions, this value can now be calculated from air analysis data alone. If this effective product is multiplied by a resistance factor for a definite cultural condition, the special effective product $W \cdot f_{Ra} = C \cdot t \cdot P \cdot f_{Ra}$ results, and this product is identical with the second tolerance limit (Figure 6).

These views have been confirmed to a great extent, but as yet not in detail. Should their correctness be supported by further experiments, then this will serve as a model by which all gaseous air impurities can be investigated with respect to their effects upon vegetation. The way will then be open for air analysis such as that fostered by Wislicenus (15). Air analysis will be not only a diagnostic measure but also will serve as a protective function in the assessment of the danger of toxicants to vegetation.

Summary

The prevention of damage to vegetation by gaseous air pollutants is only possible by means of limitations on the immissions of these phytotoxicant substances. The limitations of the immissions must be determined in such a manner that their level in the air within the habitat of the plant does not exceed fixed standards (tolerance limits).

Following the definition of the distinction between injury and damage and some discussion of diagnostic methods, a relationship is developed between damage and a tolerance limit based upon the immission and the effect of the



RELATIONS FOR THE DERIVATION OF THE SECOND TOLERANCE LIMIT

FIGURE 6

injuries. This is suggested as a basis for the critical examination of the hazard to vegetation and the evaluation of admissible emissions.

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